BACKGROUND

1. Previous Methods. Two of the approaches to the sliding stability analysis that have been used by the Corps of Engineers (CE), are the sliding resistance and shear-friction methods.

a. Sliding Resistance Method. The sliding resistance method is seldom used by the CE for current designs. This concept was the common criterion for evaluating sliding stability of gravity dams from approximately 1900 to the mid-1930's. Experience of the early dam designers had shown that the shearing resistance of very competent foundation material need not be investigated if the ratio of horizontal forces to vertical forces ($\Sigma H/\Sigma V$) is such that a reasonable safety factor against sliding results. The maximum ratio of $\Sigma H/\Sigma V$ is set at 0.65 for static loading conditions and 0.85 for seismic conditions.

b. Shear-Friction.

(1) The shear-friction method of analysis is the guidance currently used throughout the CE for evaluating sliding stability of gravity dams and mass concrete hydraulic structures. This method was introduced by Henny in 1933 (Reference 3k "Stability of Straight Concrete Gravity Dams"). The basic formula is

$$Q = \frac{S}{P} \tag{1}$$

The shear-friction method was extended in later guidance.

The total resisting shear strength, S, was defined by the Coulomb equation:

$$S = S_1 + k\ (W-U) \tag{2}$$

It is important to note that Henny considered only single, horizontal failure planes.

(2) Henny established the minimum shear-friction factor as four (4). Although the rationale for selecting this value is vague, it does appear to be the approximate average value of Q in Table eight of Reference 3k which compares the dimensions of an ideal dam, uplift forces, shear-friction safety factors, and nominal sliding factors.

(3) Records cannot be located to indicate adaptation of Henny's work into the Corps of Engineers sliding stability criteria. Nevertheless, the initial concept of defining the shear-friction factor as the ratio of the total resisting shear force acting along a horizontal failure plane to the maximum horizontal driving force can be attributed to Henny and thus technology of the 1930's.

(4) The earliest form of the shear-friction in official CE guidance is:

$$S_{s-f} = \frac{f\Sigma V + rSA}{\Sigma H}$$

This equation included a factor (r) by which S_1 was multiplied. This factor represents the ratio between average and maximum shear stresses. It was generally assumed to equal 0.5. This was a partial attempt to allow for possible progressive failure.

(5) The definition of the shear-friction factor was expanded to include the effect of inclined failure planes and embedment to resistance. The shear-friction factor, in the expanded form, was defined as:

$$S_{s-f} = \frac{R + P_p}{H} \qquad (3)$$

Equations for R and P_p were derived for static equilibrium conditions that treated the downstream wedge and structure (including any foundation material beneath the structure but above the critical path) as being separate sliding bodies. The minimum acceptable shear-friction factor (S_{s-f}) required for CE design was specified as four (4).

2. Problems with Previous Design Criteria

a. Sliding Resistance. Limitations of the sliding resistance approach are:

(1) The criterion is valid only for structures with critical sliding failure along a horizontal plane.

(2) The limiting ratio of $\frac{\Sigma H}{\Sigma V} \leqq 0.65$ was only intended for structures founded on very competent rock.

b. Shear-Friction. Limitations of the shear-friction approach are:

(1) The shear-friction factor is defined as the ratio of the maximum horizontal base resistance plus a passive resistance that is composed of shear strength and weight components, to the horizontal force actually applied. The safety factor relative to sliding stability should be applied to the shear strength of the material rather than partially strength and partially weight components.

(2) The shear-friction factor for upslope sliding approaches infinity when the angle of inclination of the failure plane is equal to an angle of (90 - ϕ).

(3) The value of passive resistance (P_p) used in Equation three was defined as the maximum force which can be developed by the wedge acting independently from the forces acting on the structure. The structure and the passive wedge act as a compatible system which is in static equilibrium.

LIST OF SYMBOLS FOR INCLOSURE 1

Symbol	Definition
A	The portion of the critical potential failure surface which is in compression.
H	The summation of horizontal service loads to be applied to the structure.
k	The factor of shearing strength increase.
P	The water pressure on the projected area of the structure assumed to move and acting on a vertical plane normal to the direction of motion.
P_p	The passive resistance of the rock wedge at downstream toe.
Q	Factor of safety of shear.
R	The maximum horizontal driving force which can be resisted by the critical path.
r	The ratio between average and maximum shear stress.
S	Total resisting shear strength acting over the failure plane.
S_1	The total shear strength under conditions of no load.
S_{s-f}	The shear-friction factor of safety.
V	The summation of vertical service loads to be applied to the structure.
U	The uplift force under the sliding plane.
W	The weight of the structure above an assumed sliding plane.